

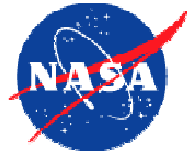
# AIR/GROUND SIMULATION OF TRAJECTORY-ORIENTED OPERATIONS WITH LIMITED DELEGATION

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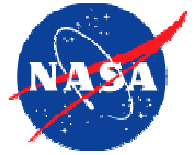
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NASA Ames Research Center  
Moffett Field, CA  
2007/6/6*

# Summary



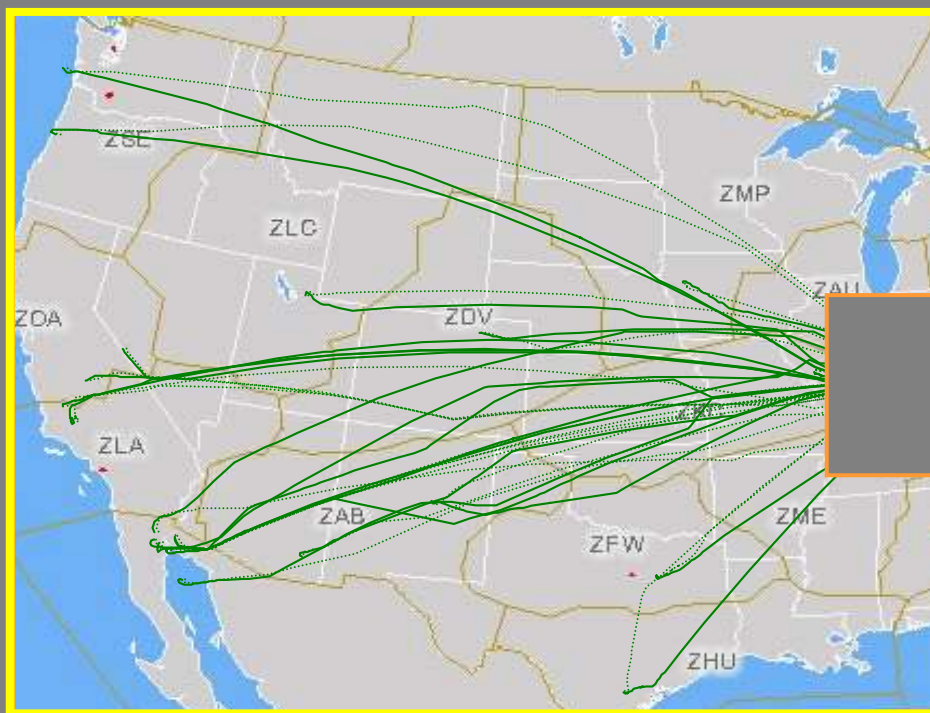
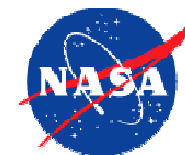
- **Simulated airspace operations with Continuous Descent Arrivals (CDA), automated arrival management, airborne spacing, controller tools, and data link**
- **Varied two flight deck conditions:**
  - *(1) with airborne spacing*
  - *(2) without airborne spacing,*
- **over three ground-side conditions:**
  - Automated Arrival Management System with*
    - *(1) current day controller displays*
    - *(2) advanced ATC scheduling and spacing tools, and*
    - *(3) the same tools integrated with controller pilot data link communication.*
- **Analyzed controller workload, safety, arrival time errors, inter-arrival spacing, energy management**

# Outline



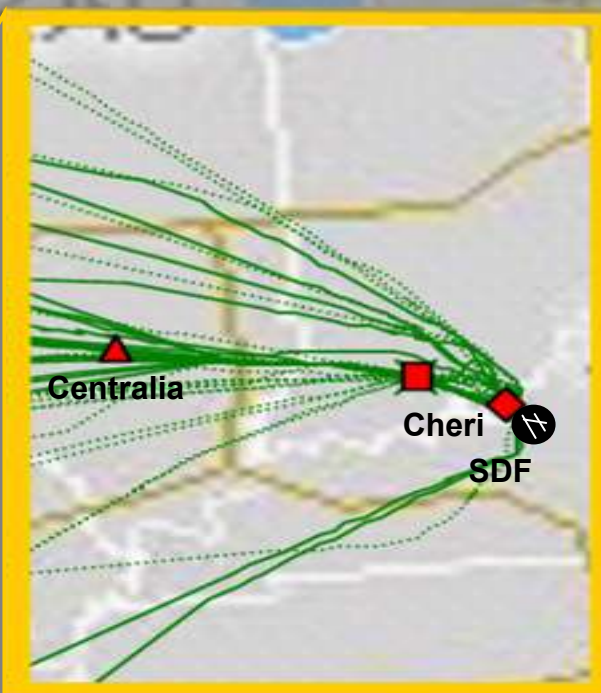
- **Background: Merging & Spacing at Louisville**
- **Trajectory-Oriented Operations with Limited Delegation (TOOWiLD)**  
**Concept of Operations for Managing Arrivals**
- **Test Airspace**
- **Experimental Design**
- **Results**
  - Feasibility: Workload, safety, CDA success rate
  - Runway throughput: Inter-arrival spacing with and without airborne spacing
  - Accuracy/predictability: Arrival time errors at the threshold
  - CDA efficiency: Energy management along the CDA
- **Concluding Remarks**

# Background: Flight Deck-Based Merging & Spacing (FDMS) Concept with Airline-Based Sequencing and Spacing (ABESS) at SDF



## •M&S En Route Operations

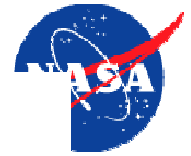
- Inbound aircraft are “preconditioned” using GOC speed advisories based on sequence and spacing at en route merge fix. Spacing advisories may also be assigned. Advisories are sent to the flight deck using ACARS.
- Little-to-no ATC involvement.



## M&S Arrival Operations

- Aircraft that are within ADS-B range may engage airborne merging and spacing.
- “Preconditioned” SDF arrivals are cleared by ATC for CDAs.
- Little-to-no ATC involvement.

# TOOWiLD\* Concept of Operations for Managing Arrivals During Simulation



7<sup>th</sup> USA-EUROPE ATM R&D Seminar, July 02-05, 2007, Barcelona, Spain

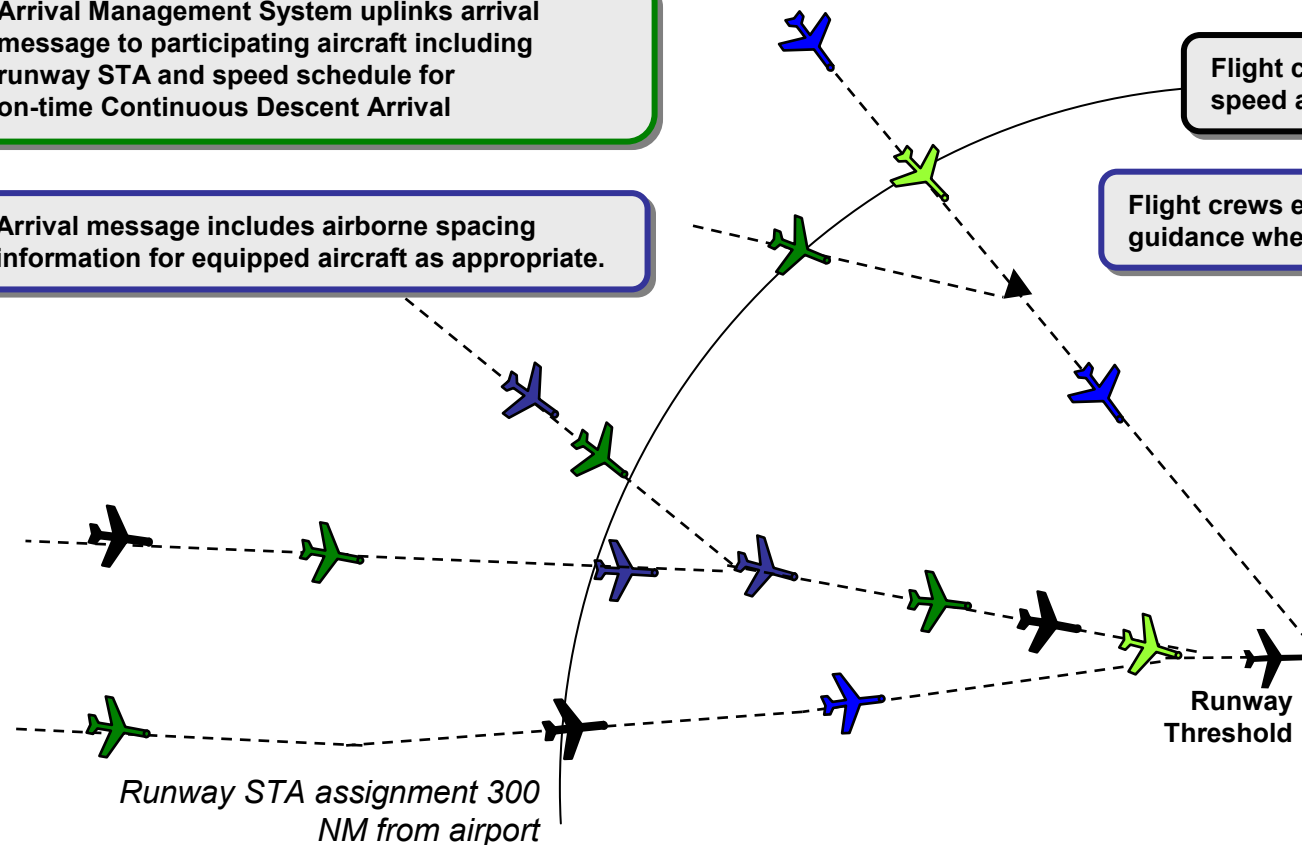
Arrival Management System uplinks arrival message to participating aircraft including runway STA and speed schedule for on-time Continuous Descent Arrival

Arrival message includes airborne spacing information for equipped aircraft as appropriate.

Flight crews execute clearances and speed advisories.

Flight crews engage and follow spacing guidance when within ADS-B range.

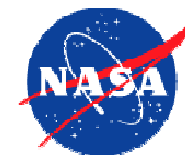
Controllers monitor all arrivals.



Controllers issue CDA clearances, are informed about airborne spacing of participating aircraft and intervene if required for separation, and manage non-participating aircraft

\*TOOWiLD: Trajectory-Oriented Operations With Limited Delegation

## ACARS arrival information message

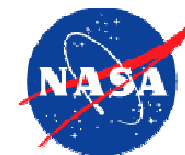


- **At the STA freeze horizon (300 NM from the airport) an arrival information message is sent by the automation via ACARS:**

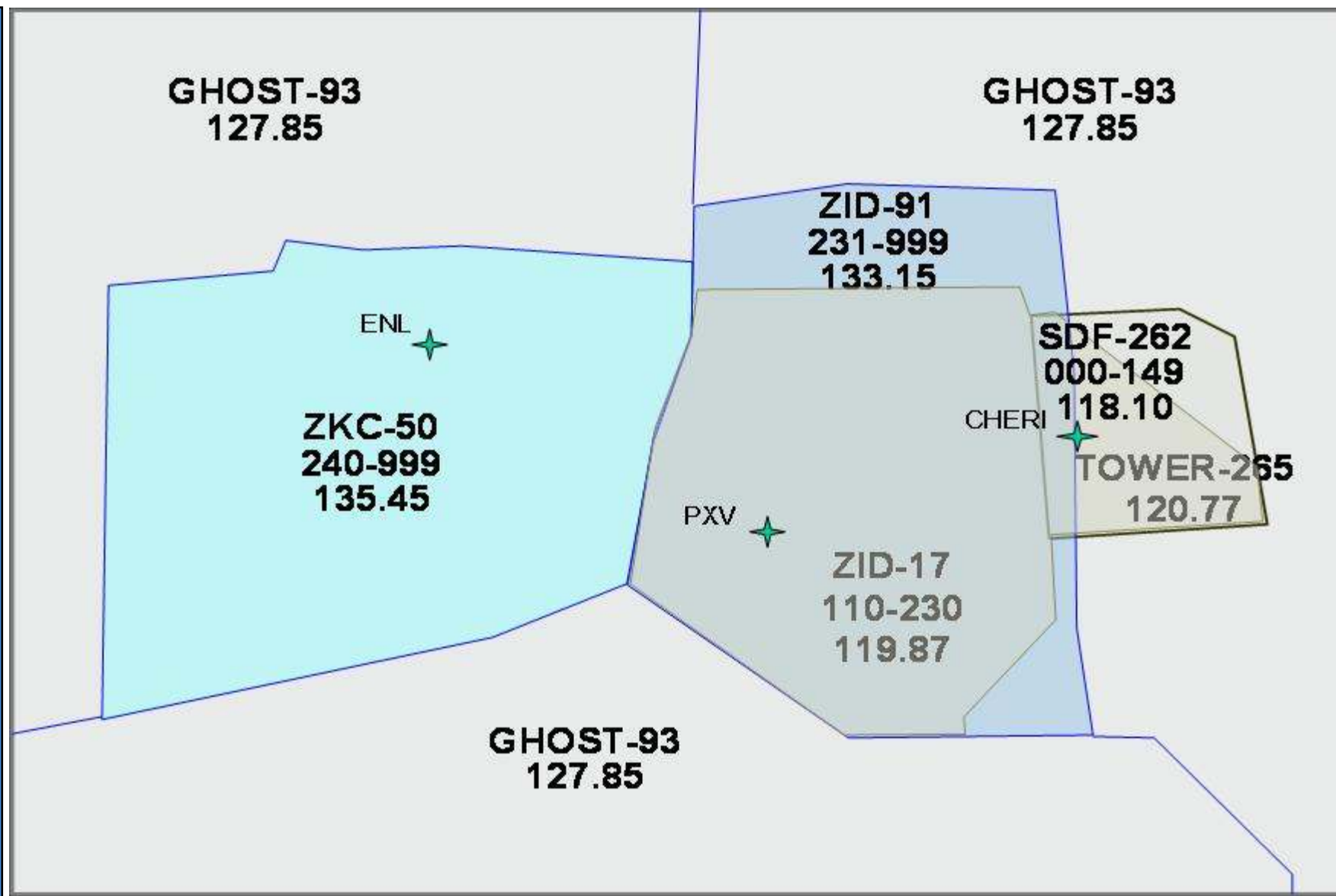
```
"SDF ARRIVAL UPS913  
17R AT 17:03:20 UTC  
CRZ .78 DES .78/275  
LEAD: UPS907  
MERGE PT: CHERI  
SPACING: 105 SEC"
```

```
"SDF ARRIVAL UPS913  
17R AT 17:03:20 UTC  
CRZ .78 DES .78/275"
```

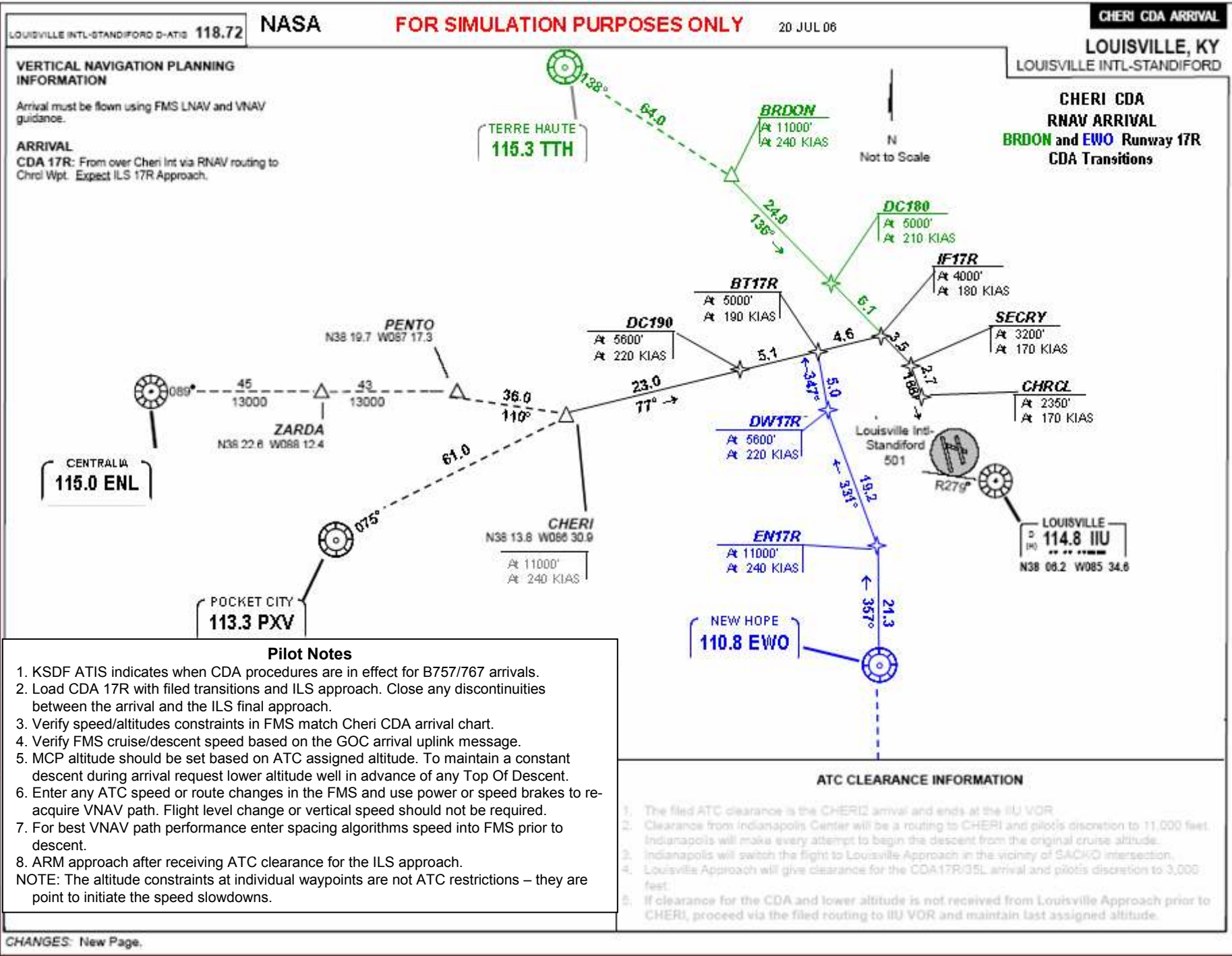
# TOOWiLD Simulation Airspace



7<sup>th</sup> USA-EUROPE ATM R&D Seminar, July 02-05, 2007, Barcelona, Spain

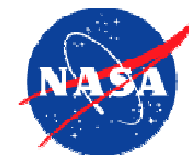








# Experimental Design



- **September 2006 NASA Ames Research Center**
  - Airspace Operations Lab
  - Flight Deck Display Research Lab
- **Participants**
  - 4 radar certified controllers (3 ARTCC, 1 TRACON)
  - 8 airline pilots (3 current UPS pilots)
- **Traffic**
  - Extended UPS night-time arrival push mixed with day time crossing traffic (mixed equipage)
  - 2 Scenarios at high current day traffic levels
- **12 Data Collection runs**
  - Two basic Scenarios. each ~75 minutes
- **2 Flight Deck conditions:**
  - Current day FMS & ADS-B out
  - +Airborne spacing for 70% of UPS aircraft (Eurocontrol Co-space logic)
- **3 ATC Workstation conditions:**
  - Arrival management system with current day displays
  - +ATC tools for sequencing and spacing
  - +ATC tools integrated with data link

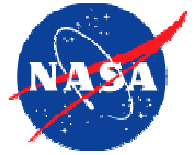


# 6 Conditions simulating different Flight Deck and ATC equipage levels



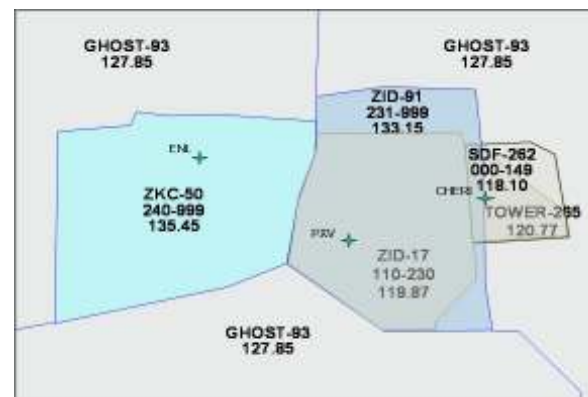
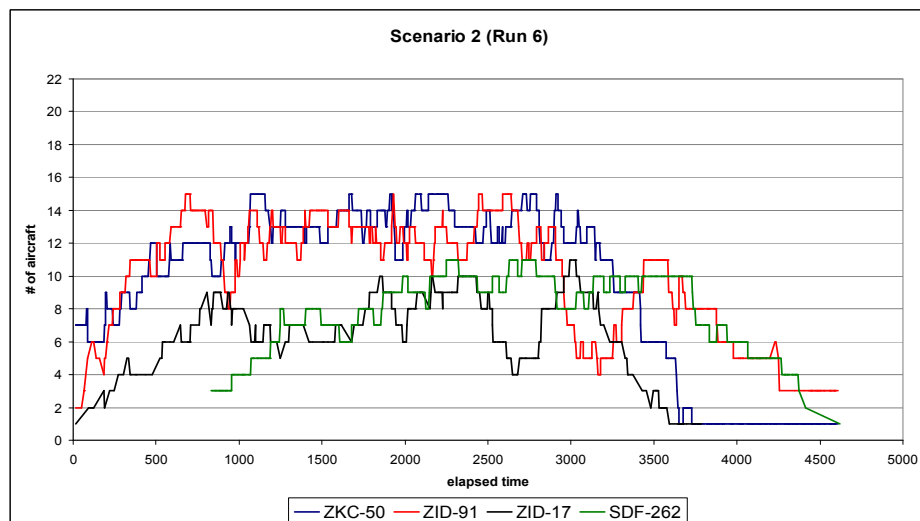
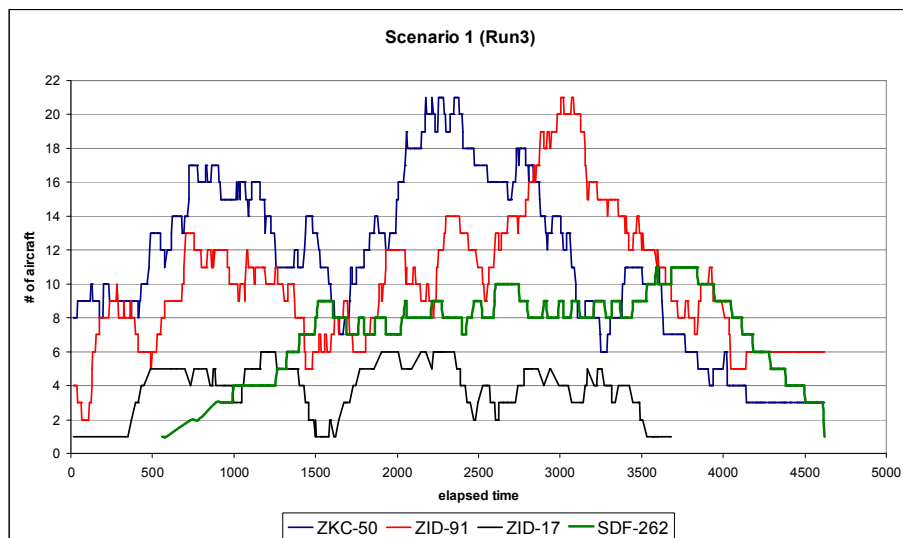
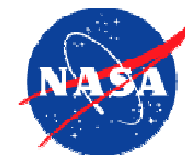
Flight Deck equip. ATC equip.	FMS (RNAV)	+ Airborne Spacing
Arrival Management System	CDA's with automated sequencing & spacing	CDA's with automated sequencing & spacing and airborne spacing
+ ATC tools	CDA's with automated sequencing and spacing and time-based metering by ATC	CDA's with automated sequencing and spacing and time-based metering by ATC and airborne spacing
+ controller pilot data link communication	CDA's with automated sequencing and spacing, time-based metering by ATC and CPDLC	CDA's with automated sequencing and spacing, time-based metering by ATC and CPDLC and airborne spacing

# Result Summary



- **It seems possible to conduct continuous descent arrivals in high density airspace.**
  - Acceptable workload, safe, very little vectoring
- **Airborne spacing has positive effect on runway throughput and no negative impact on on-time arrivals.**
  - Better inter-arrival spacing, equal arrival time accuracy
- **The highly automated arrival management concept was very effective in all conditions.**
  - Good arrival time accuracy
- **ATC tools reduce the mean error for non-participating aircraft and reduce the variability of all aircraft**
  - Higher arrival time accuracy with ATC tools
- **Energy management remains a primary issue to be addressed.**
  - Relative energy along CDA

# Traffic Count (Scenario 1 and 2)



2 complex scenarios at high traffic densities.

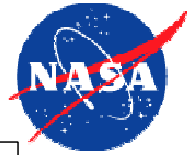
High altitude: 10-21 aircraft

Low altitude: 5-10 aircraft

Approach: 7-12 aircraft

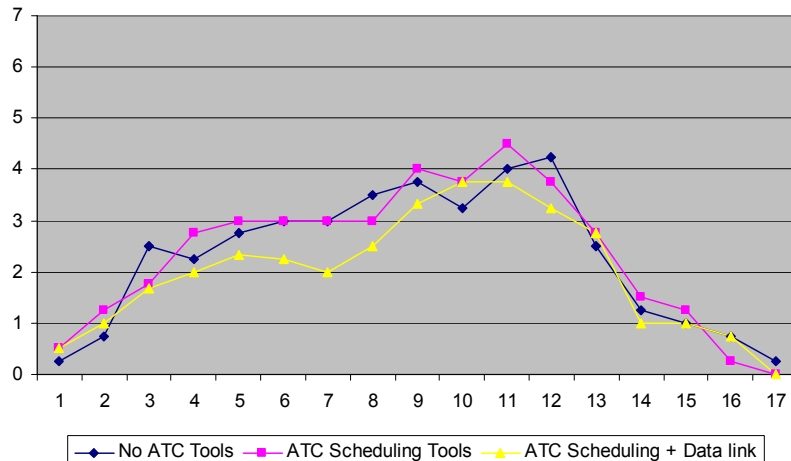
During these traffic conditions 96 % of arrivals flew the CDA approach routing and did not receive a heading vector below 11.000 feet

# Controller Workload by ATC condition

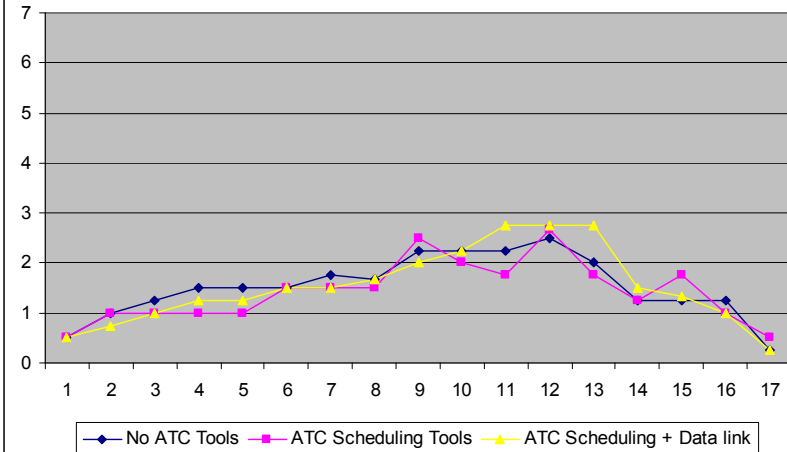


7<sup>th</sup> USA-EUROPE ATM R&D Seminar, July 02-05, 2007, Barcelona, Spain

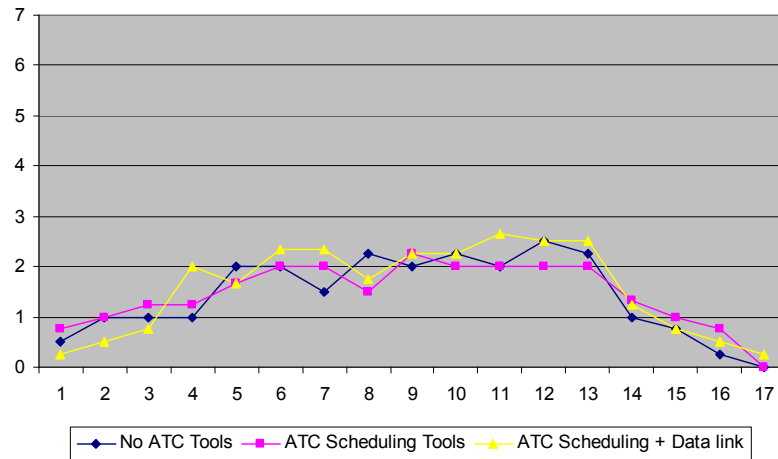
Average Workload by ground tools ZKC50



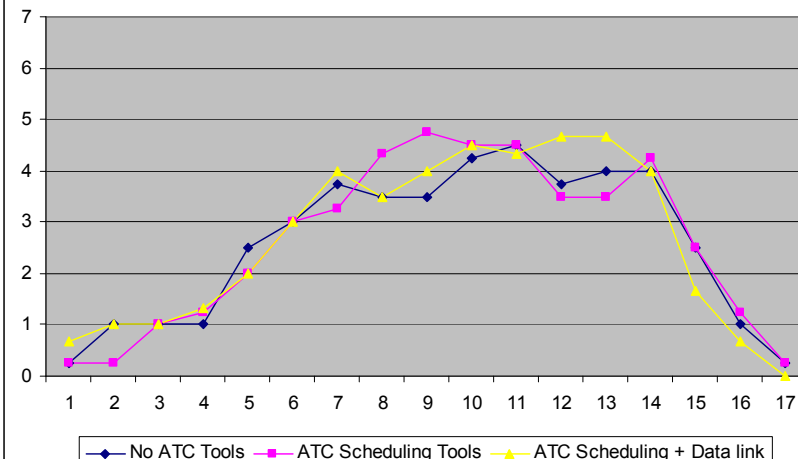
Average Workload by ground tools ZID91



Average Workload by ground tools ZID17

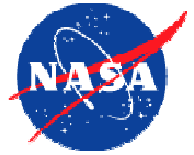


Average Workload by ground tools SDF262

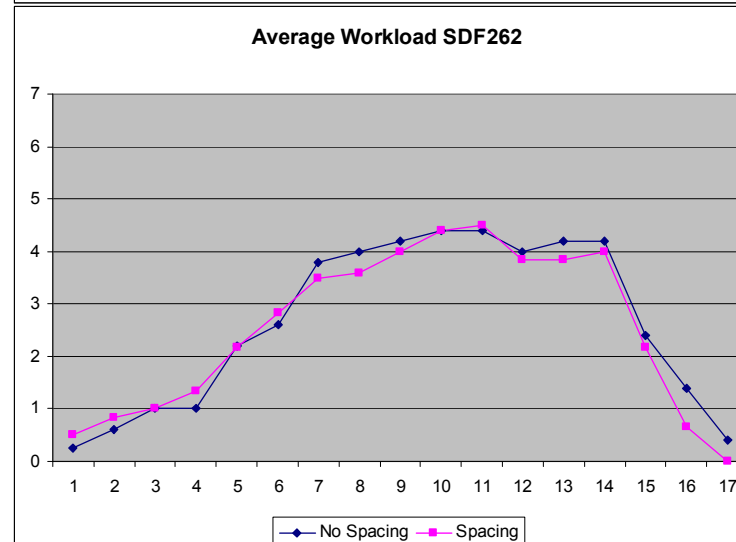
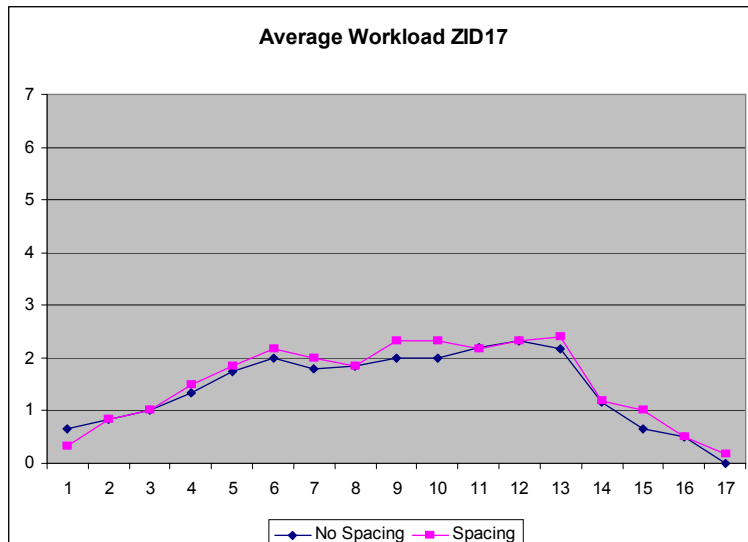
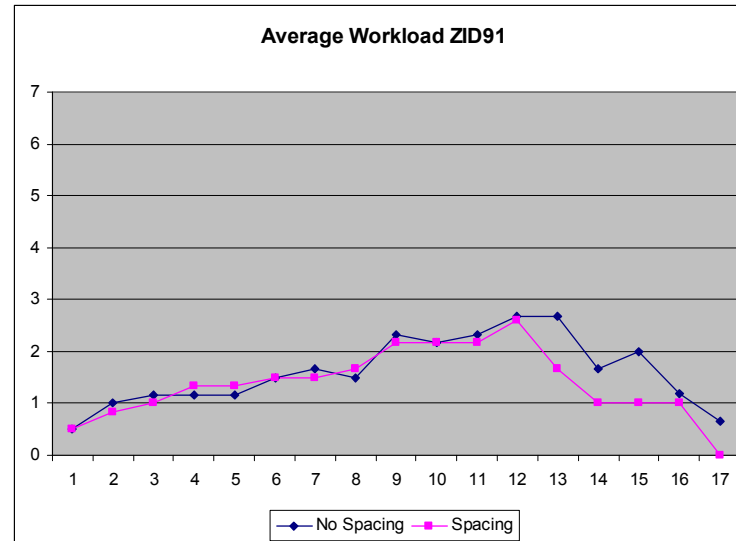
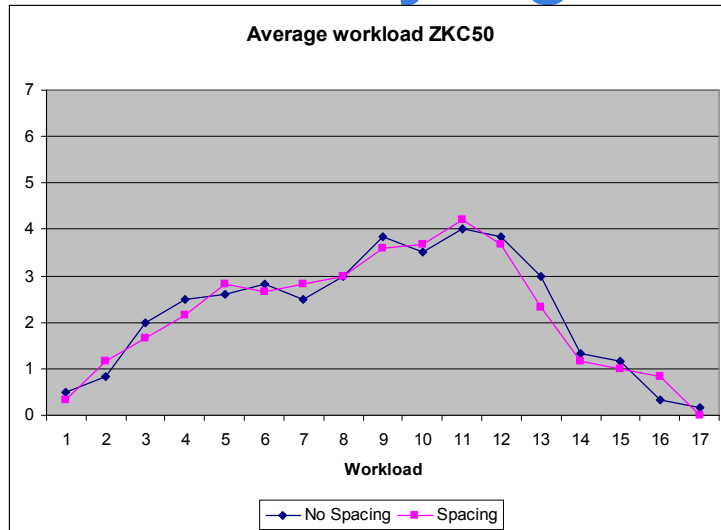


Controller workload was manageable and followed primarily traffic count.  
No impact from ATC condition in mixed equipage environment

# Controller Workload by flight deck condition

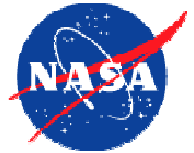


7<sup>th</sup> USA-EUROPE ATM R&D Seminar, July 02-05, 2007, Barcelona, Spain



Controller workload was manageable and followed primarily traffic count.  
No impact from airborne spacing in mixed environment

# Safety



## Separation violations by condition:

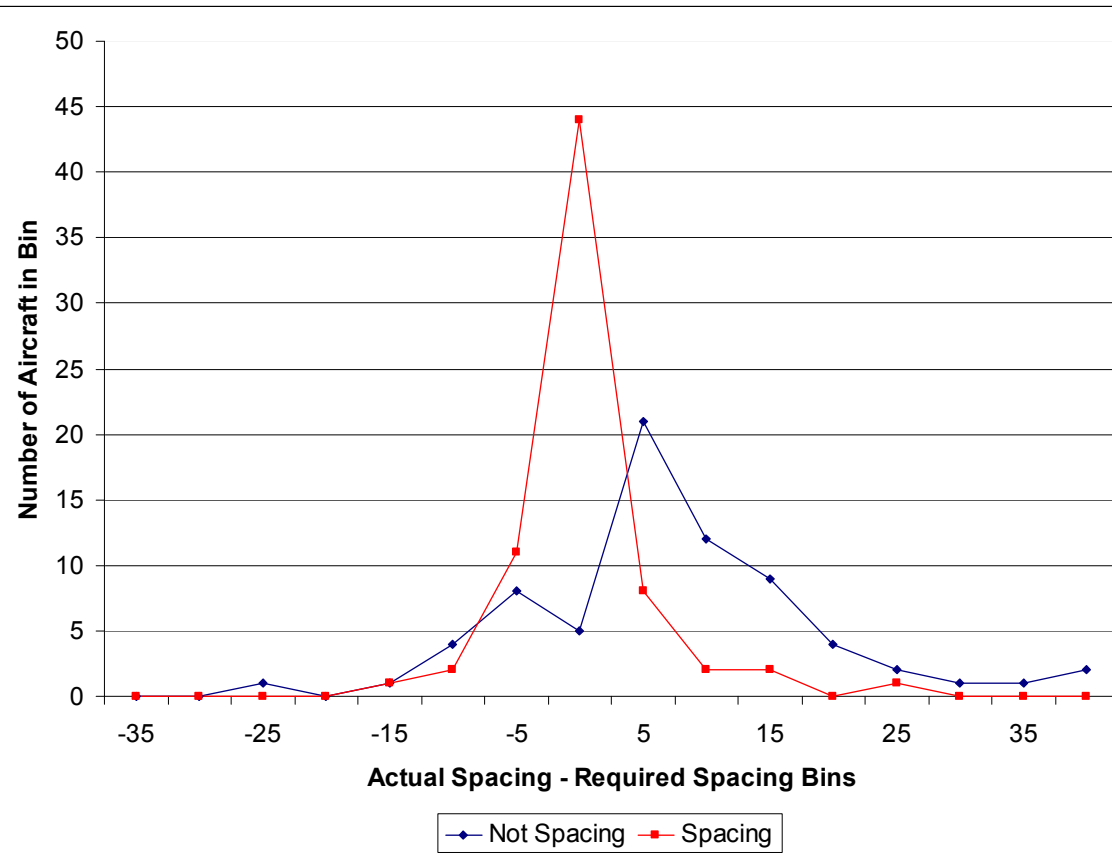
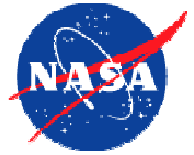
	FMS/CDA	+Airborne spacing	Total
Arr. Mgmt. Sys.	1 (1)	0 (3)	1 (4)
+ATC tools	0 (1)	1 (2)	1 (3)
+Data link	0 (1)	0 (1)	0 (2)
Total	1 (3)	1 (6)	

- The 1st value refers to violations lasting for at least 12 seconds (RADAR sweep), the 2nd value to violations of less than 12 seconds.
- Only one Louisville arrival involved in separation violation

All operations were considered safe by all participants. The observed separation violations were short and simulation related (multi-pilot errors)



# Inter-arrival spacing at the runway - arrival peak -



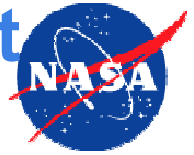
mean and  
variance of inter-  
arrival spacing at  
the runway was  
significantly  
reduced

$(t(70) = 3.95,$   
 $p < 0.001,$   
 $F(70,70) = 8.38,$   
 $p < 0.001).$

	Current day	Airborne Spacing
Spacing error (seconds)	6.3 (15.6)	-1.5 (5.4)

Airborne spacing produced very precise relative spacing at the threshold,  
and therefore can increase runway throughput

# Arrival time accuracy for participating aircraft - all participating arrivals-



Actual– scheduled time of arrival at runway, mean (and standard deviation) in seconds

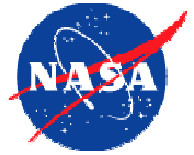
	FMS/CDA	+Airborne spacing	Total
Arr. Mgmt. Sys.	-2.2 (30.4)	3.3 (53.0)	0.5 (43.0)
+ATC tools	4.1 (15.6)	-7.8 (11.1)	-1.8 (14.7)
+Data link	13 (37.4)	-0.02 (24.7)	6.5 (32.1)
<b>Total</b>	<b>5.0 (29.8)</b>	<b>-1.56 (34.7)</b>	

- airborne spacing shows marginally significant lower mean ( $t_{\text{two-tailed pair-wise}}: (124) = 1.8; p < 0.07$ ).
- ATC-tools reduce variability ( $F(83,81) = 8.53, p < 0.001$ )
- Arrival Management System accounts for main effect

The automated arrival management system was able to organize the arrival flow such that most aircraft arrived within 30 seconds of their arrival time, which was assigned 40 minutes before touchdown

# Arrival time accuracy

## - all non-participating arrivals -



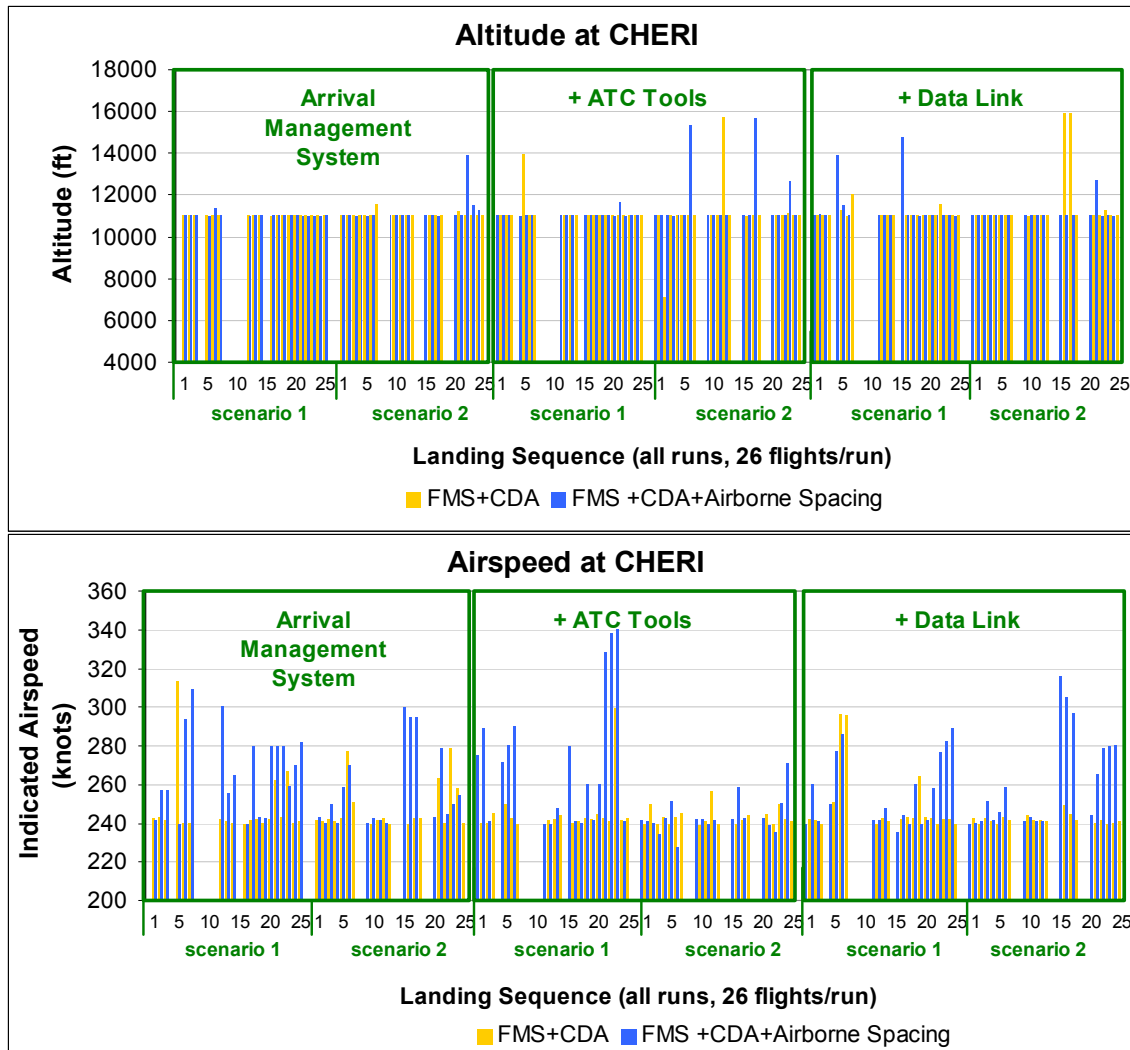
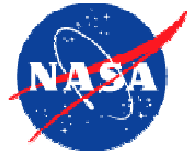
**Actual– scheduled time of arrival at runway,  
mean (and standard deviation) in seconds**

	<b>FMS/CDA</b>	<b>+Airborne spacing</b>	<b>Total</b>
<b>Arr. Mgmt. Sys.</b>	-26.2 (52.8)	-28.7 (55.5)	<b>-27.3 (50.3)</b>
<b>+ATC tools</b>	-2.1 (27.2)	-0.8 (18.8)	<b>-1.5 (22.7)</b>
<b>+Data link</b>	-2.9 (26.0)	-0.7 (33.3)	<b>-1.8 (29.1)</b>
<b>Total</b>	<b>-10.4 (37.9)</b>	<b>-9.75 (37.7)</b>	

- **No effect of airborne spacing**
- **without controller tools non-participating aircraft arrived on average 26 seconds earlier than in the tools condition ( $t(23) = -2.1, p < 0.047$ ) with a much larger variability ( $F(18,39) = 3.8, p < 0.001$ )**

**ATC tools connected to the arrival management system enabled controllers to manage the arrival time of non-participating aircraft more precisely**

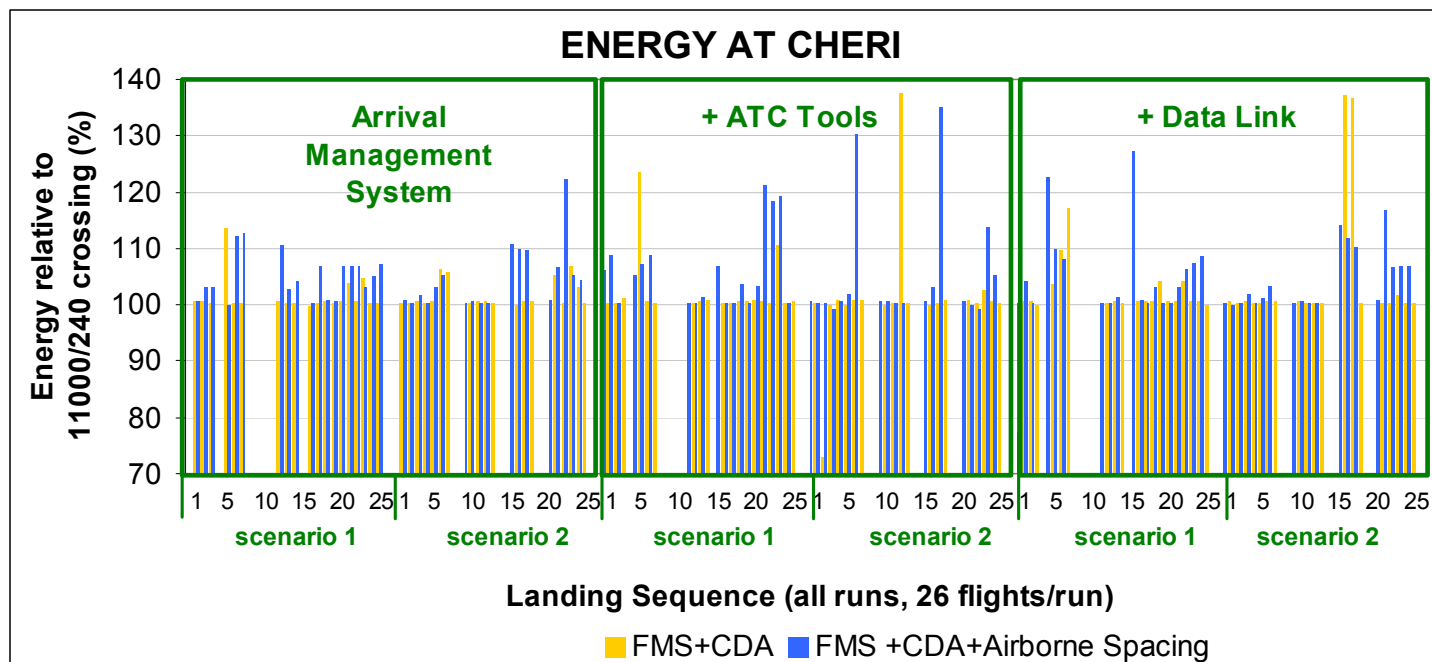
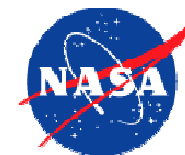
# Energy management – speed and altitude at CHERI



- Nominal crossing at CHERI was 11000 feet, 240 knots
- Controllers and pilots were briefed that airborne spacing speed would take precedence over speed on CDA
- Good altitude compliance, peaks indicate problems with getting clearance on time
- Speed varies in airborne spacing condition

Speed adjustments during the initial idle descent portion resulted in aircraft being high or fast at the first crossing restriction

# Energy management – Relative energy at CHERI

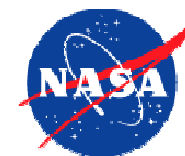


**Relative energy:**  
actual energy as  
a percentage of  
nominal energy  
for CHERI  
crossing  
restriction  
(240/11000)

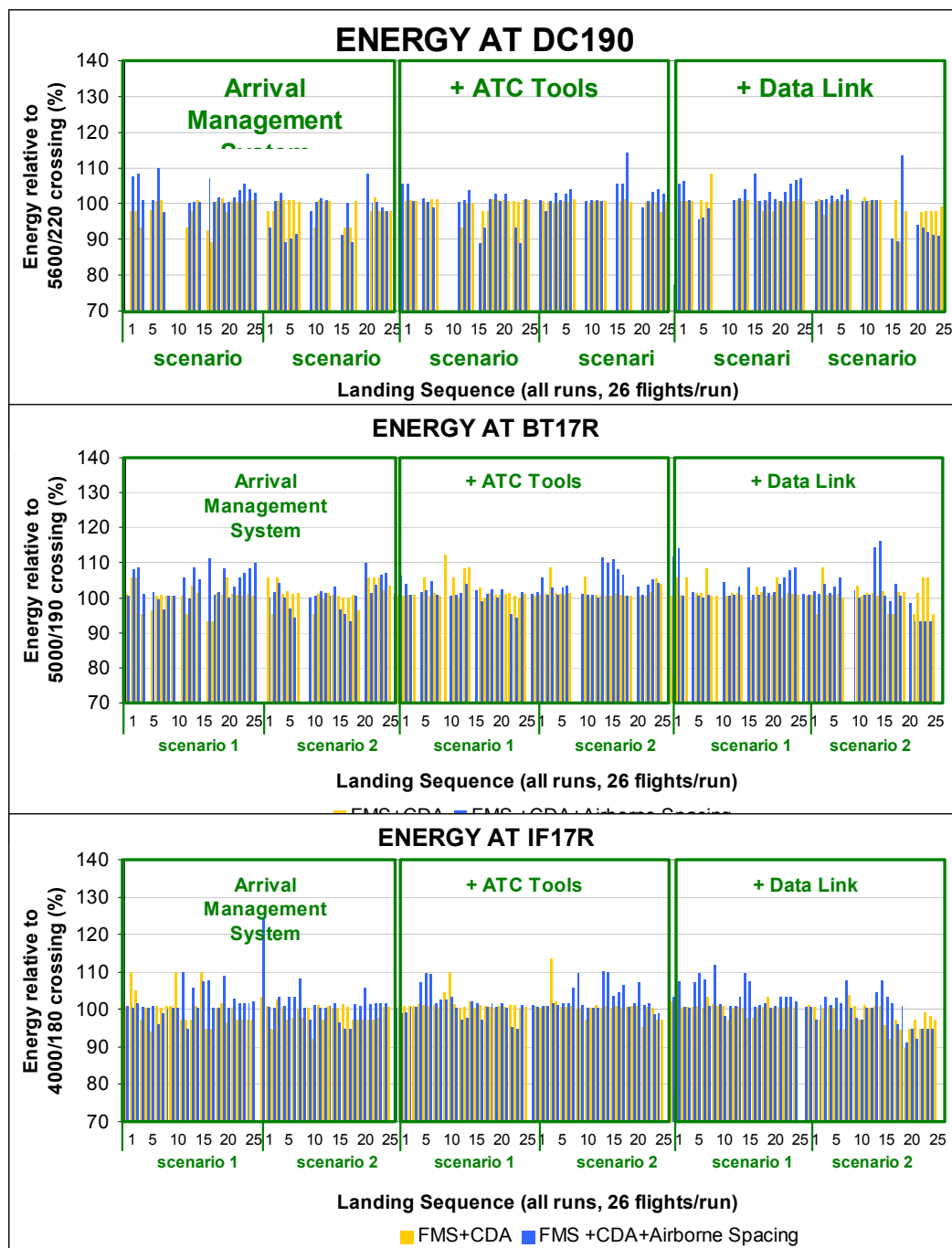
**Aircraft  
conducting  
airborne spacing  
had a  
significantly  
higher relative  
energy mean at  
CHERI (t (58) =  
4.2; p < 0.001).**

	FMS/CDA	+Airborne spacing	Total
Arr. Mgmt. Sys.	102.2 (2.5)	107.4 (5.1)	104.8 (4.7)
+ATC tools	102.5 (5.3)	109.1 (10.0)	105.6 (8.6)
+Data link	104.4 (8.9)	107.5 (6.1)	105.9 (8.1)
Total	102.9 (6.1)	108.8 (7.7)	

**Hardly any aircraft was low on energy, which is typical at the first crossing restriction after an idle descent.**



# Energy management – Relative energy inside the TRACON

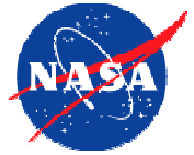


Base  
turn

Final  
turn

The CDA's were designed with nominal lower power segments during approach. The excess energy from the initial crossing restriction was largely absorbed downstream of CHERI

## Concluding Remarks



- **It seems possible to conduct continuous descent arrivals in high density airspace.**
- **Airborne spacing has positive effect on runway throughput and no negative impact on on-time arrivals.**
- **The highly automated arrival management concept was very effective in all conditions.**
- **ATC tools reduce the mean error for non-participating aircraft and reduce the variability of all aircraft.**
- **Energy management remains a primary issue to be addressed.**